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TASTES AND ODORS FROM CHLORINATION[1]

By Walter A. Sperry[2] and Lloyd C. Billings[3]

Part I. General discussion

It is the purpose of this paper not so much to present new material as to relate Grand Rapids' experiences in the matter of chlorine feeding and tastes. As we view this whole problem the most practical suggestions as to the feeding and control of chlorine have come from the writings of Abel Wolman of the Maryland State Department of Health.

Chlorine has been at once the operators' great benefactor and sore trial, as he has sought to preserve public health and avoid public condemnation through its use. All have felt the constant need of such methods of control as would assure a safe water without the constant danger of tastes.

The Wolman chlorine absorption method of test, along with his residual chlorine test appears to meet this dual problem. At Grand Rapids, we have followed, for the most part, a plan of "invariable dosage." We have always felt its inadequacy. Tastes have developed when none were looked for and conversely. Disinfection has not always been satisfyingly complete. Limiting quantities producing tastes have been variable and puzzling.

For the past two years daily studies as to the chlorine absorption values of our raw, settled and tap water along with their oxygen consumed values have been made in the hopes of finding a more logical control than that of which we were making use. They have led us to believe more and more in the final fitness of the methods cited to this end.

Provisions made in original design for the proper reception of chlorine may prove a legitimate cause for taste. The problems of design are complex and one thing is and often must be sacrificed for another. To the older plants chlorine has come as an afterthought. In most of the new the operator is left to apply his chlorine as best he can. Whereas it may seem the most favored practice to add this reagent to the clear-well following filtration there may be no means, as a collector main, for accomplishing this and the conduits leaving the clear well may be so immediately connected to the city mains as to leave too short a time interval for its proper absorption and effects. There may further be no means of knowing the rate of flow at such a point as will provide the necessary control, so that the chlorine must be applied at a constant disadvantage.

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[1] Read at the Cleveland Convention, June 8, 1921. Discussion is invited and should be sent to the Editor.

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This point of variation in design brings a secondary problem to the State Board of Health official who, in seeking uniform standards of quality in all the plants under his supervision, desires or demands a uniform point of application for chlorine. Either his rule must be set aside from plant to plant or one plant can comply with more efficiency with regards to disinfection effected and number of times for taste development than another. The favorableness of the place provided for the reception of chlorine undoubtedly has something to do with the quantity required and this again is a factor in the frequency of taste appearance.

In the Grand Rapids plant water from the river passes a venturi meter; is received in a stilling or distribution chamber; passes to one of two mixing chambers and thence to settling basins.

Water from the settling basins passes into a collecting passage and enters the individual filters through a 48″ distributor main. Five of the existing filters individually discharge directly into a 0.35 million gallon clear-well. The other five similarly discharge into a 2.44 million gallon well. The water from the clear-wells discharges at points opposite each other and into a 48″ conduit, 2800 feet long, that conveys the water to the high service pumping station.

This arrangement admits of but one possible point for applying our chlorine with safety as regards its control. It must be applied in the upper passage leading from the settling basins to the filters and at a point as far removed from the filters as that it will meet the discharge from both basins, so as to insure its complete contact with the whole volume of water before entering the filters.

This is our only means of getting our chlorine into the water in the clear-well. It has an advantage which we accept and think well of—that of keeping the filters sterile—possibly preventing to a certain extent bacterial growths therein. Its control is based upon the indications of the venturi meter. It has the possible disadvantage of requiring a larger dosage than might be required could we apply it to the clear-wells direct. In this larger dosage lies more possibilities of taste than with smaller doses, as will be pointed out later. Such periods of taste as we experience now seem possible of elimination through the rational methods of laboratory control cited.

We have no collecting main between our filters and the clear-well that offers this possibly most favorite point for applying chlorine. We are entirely unable to make use of the conduit leading to the high service station, by reason of the entire absence of any metering device whatsoever by which the flow therein may be known. The flow therein is widely variable and entirely unrelated to the input to the filter plant from the river.

Under Grand Rapids plant conditions, therefore, we are limited to one possible point of application and would be entirely unable to meet with safety any State Board request for chlorine application other than before filtration.

This plant further seems to have experienced less occasion of taste from the use of hypochlorite than when using liquid chlorine. It was originally designed to use hypochlorite. At that time chlorine feeding devices had not reached a state of perfection that made their use seem advisable and our original design has proved so satisfactory and our proximity to sources of production of hypochlorite are such that we have preferred to use it ever since.

However through the greater part of 1918 and 1919 liquid chlorine has been used entirely or in conjunction with hypochlorite. During this period we have experienced more frequent occasions of taste than ever before or since. It should be stated that during this time radical changes in our methods of using lime demanded a marked increase in the amount of chlorine applied and for a time we attributed our frequently occurring tastes to this fact. Since then however after the discontinuance of the liquid chlorine the larger dosage of chlorine required in the hypochlorite form has again given much less frequently occurring tastes. We were constantly in trouble in 1919 particularly during the summer and quite free from trouble in 1920.

The final reason for this has only lately occurred to us and is rather different than what might be expected. When applying liquid chlorine a 100 per cent solution is made use of. Where the dosage required is large, especially in view of the fact that there is a very small range between the amount required for proper disinfection and that necessary to produce taste, any small fluctuation of the dosage with so concentrated a reagent throws one into the taste zone. With hypochlorite this danger is lessened or one has a greater factor of safety due to the fact that the solutions are much more dilute and over-dosing, accidentally or otherwise, can take place with much less danger of tastes. At Grand Rapids we carry a 0.5 per cent solution of hypochlorite or a 0.16 per cent solution of available chlorine.

As far as our experience goes we believe that in all cases tastes and odors are due to larger applications of chlorine than necessary to produce satisfactory disinfection. If the dosage in each case were correctly adjusted to the water, tastes would not occur. This statement applies to our own experiences and we believe it to be generally applicable to filtration plant practice.

An incident occurred in June, 1913, that lends interesting color to this discussion. Such a pronounced chlorine taste developed in the delivered water in certain portions of the city one evening that a prolonged and vigorous protest resulted. For three days it persisted as it invaded territory further out on the distribution system until it finally disappeared. In the meantime absolutely nothing could be found that explained how it had occurred. The records were regular and clear both as to tank strengths and the rate of application. No taste during any of this period showed up at the plant. The water in our clear-wells was sweet and good as it was also in the low service reservoir nearby. We were entirely without the key to the situation until it was recalled that the morning of the day the tastes occurred a "cleanup" of the lime storage tower had been ordered. On the floor above the bins our hypochlorite casks were stored. Several inches of quick lime dust which had been accumulating here for some time were swept up and dumped into the raw water to save it. This quick lime proved a veritable hypochlorite factory. The conditions were similar to those of actual hypochlorite manufacture. The quick lime had absorbed chlorine distilling off the casks of hypochlorite stored there and so converted it to fresh hypochlorite that its addition to the water constituted a large "spot" over-dose in the raw water that passed through the plant and entered the system before it was detected.

This was our first serious mishap in the early days of the plant. It scared the city most to death. We turned it to good account by admitting the situation and giving the papers a clean straight story. The admission and confession did more generally to establish confidence than anything that could have happened. We profited by it through three or four years and even today it has not been entirely forgotten.

Part 2. Experimental data

Laboratory tests covering a period of sixteen months show some interesting comparisons. Figure 1 shows the comparative chlorine absorption values obtained by daily tests on river, settled and filtered waters. Turbidity and oxygen consumed values of river and settled waters are also given. These are monthly averages extending over a period from January 1, 1920 and through April 1921.

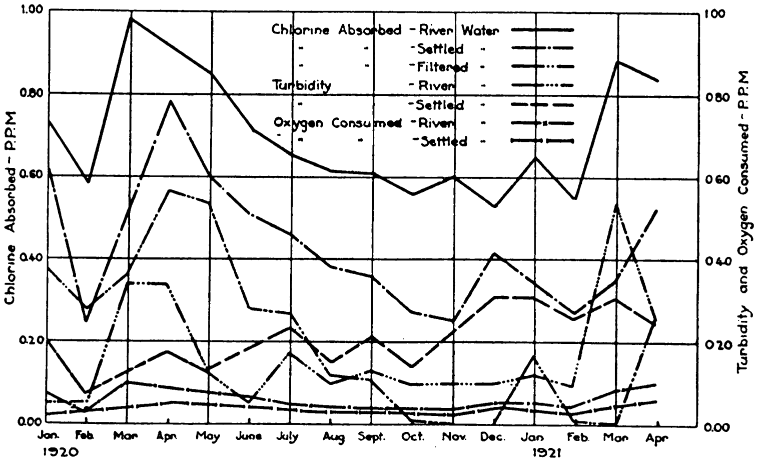

FIG. 1. COMPARISON OF CHLORINE ABSORPTIONS WITH OTHER CHARACTERISTICS OF GRAND RAPIDS WATERS

The river water chlorine absorption figure remains quite high throughout the year, being lowest through the summer, fall and early winter months. The range of absorption is from 0.98 p.p.m., a flood time period, to 0.53 p.p.m., when the river water has its minimum turbidity.

The settled water curve appears to follow the general trend of that of the river. It lies somewhat below, but parallels, the variations to which the river water is subject, because chemical treatment has not produced the proper coagulation to make it a low, straight line curve. When a full continuous lime treatment is followed, coagulation of the settled water is better and the chlorine absorption curve approaches a low approximate straight line. But at Grand Rapids the intermittent lime treatment plan is followed which results in chlorine absorption values in the settled water as indicated by the curve. A special study of a series of chlorine absorption experiments in which hourly tests were made on the settled water during plant operation, shows slight varying chlorine absorption values. The variation consists of consecutive high and low values, i.e., high one hour and low the next, etc. This difference from hour to hour does not appear to be more than 0.1 or 0.2 p.p.m. and probably could be disregarded when calculating a chlorine dose.

Since in plant operation at Grand Rapids the chlorine is fed into the settled water immediately before filtration, the chlorine absorption test on such water becomes of considerable importance as a control medium for the chlorine feed. Although the plan of using the chlorine absorption method has not been adopted as a regular procedure it bids fair to be made use of to a considerable advantage in the near future. Briefly, the plan to follow, would be to obtain the chlorine absorption figure by the 5-minute test on the settled water and then calculate the proper dose of chlorine to be fed, such dose to include sufficient chlorine for absorption and enough additional to leave some residual chlorine at one of the filter effluents. This residual chlorine should be sufficient to disinfect and yet leave no taste in the treated water.

Wolman and Enslow,[4] put forth the hypothesis "that a proper dosage for the effective disinfection of a water was an amount equal to that absorbed by the water tested after contact of 5 minutes plus a factor of safety of 0.2 p.p.m. (as a tentative value)." In *Engineering News-Record,*[5] page 639, Wolman reports the working out of this hypothesis on a practical scale at Luke, Md. He shows that, from observations covering a period of 2 years at this place, the factor of safety of 0.2 p.p.m. is practicable. He suggests further that local conditions may govern the selection of a factor of safety along with the varying period of test, but that the fundamental principle of chlorination control should remain the same.

[4] Wolman and Enslow, *Jour. Ind. and Eng. Chem.*, vol. 11, no. 3, March, 1919.

[5] Wolman, *Engineering News-Record*, vol. 86, no. 14, April 14, 1921.

We at Grand Rapids are of the opinion that it will be necessary to select some other factor of safety than 0.2 p.p.m. and test more than 5 minutes from the point of application. This is because of the physical impossibility of selecting a point which is 5 minutes of water travel from the point of application of chlorine. Yet from what observations have been made, we are confident that the principle can be applied advantageously and the control can be manipulated at one of the filter effluents. One daily chlorine absorption test on settled water would be sufficient to control chlorine feed.

Approximately one third of the time indicated by the curves the filtered water tested zero chlorine absorption or else indicated some residual chlorine. Unfortunately these residual chlorine values were not recorded, so in the following data, whenever the filtered water showed no chlorine absorption it was so recorded with no respect to residual chlorine which may or may not have been present.

The number of days in which zero chlorine absorption value was recorded is indicated for the following months, 1920, January—2 times, February—1, March—1, June—1, July—6, August—12, September—10, October—19, November—16, December—10, 1921, January—7, February—16, March—22 and April—6.

One very significant fact is that all taste troubles experienced, occurred during the months of August, September, October and November. It is interesting to note also that the bacterial quality of the water delivered to the mains during those months in which there was zero chlorine absorption in the filtered water a large per cent of the time, and when taste troubles occurred, was much superior to that delivered during the other months of the year.

In all probability had the chlorine absorption method of control been applied at the time of these taste troubles the difficulty might have been obviated.

The flood time demand of the settled water is quite often far in excess of the chlorine feed. The result is an inferior filtered water bacterially. This would call for an increase in the chlorine feed but not enough to entirely satisfy demands of the settled water. We were reluctant to raise the chlorine up to the high figure on account of fear of taste. On the other hand during the months of August, September and October with an invariable dosage we naturally ran into taste trouble, because the chlorine demands of the settled water became much less. This has resulted in a chlorine treatment which has been unwieldy, slow of manipulation to meet changed conditions and many times unsatisfactory as a disinfectant and occasionally an annoyance because of taste difficulties.

The above curves, coupled with the following discussion, clearly indicate that the chlorine absorption method of chlorine feed control may be applied very advantageously, thereby producing a better water bacterially and allowing feedom from tastes all the year.

The turbidities of river and settled water appear to be followed in a general way by the chlorine absorption values. The relation-

Experiments to determine chlorine figures and taste limits of various waters

Method. 2000 cc. volumes of water used. Chlorine added by means of a dilute solution of calcium hypochlorite. Chlorine allowed to act 5 minutes. Residual chlorine determined and taste observations made.

WATER	TURBIDITY	CHLORINE ABSORBED	DOSE	RESIDUAL CHLORINE THEORETICAL	RESIDUAL CHLORINE BY TEST	ODOR	TASTE
	p.p.m.	*p.p.m.*					
River.......	22	1.00	1.10	0.10	0.05	None	None
			1.20	0.20	0.10	None	None
			1.30	0.30	0.10	None	None
			1.50	0.50	0.40	None	None
			1.70	0.70	0.20	None	None
			1.90	0.90	0.20	None	None
			2.10	1.10		None	Faint
Settled......	20	0.55	1.05	0.50	0.50	None	None
			1.30	0.75	0.75	None	None
			1.55	1.00	1.00	None	None
			2.05	1.50	Beyond stand	None	None
			2.55	2.00		None	Faint
Filtered.....		0.35	0.55	0.20	0.20	None	None
			0.75	0.40	0.40	None	None
			0.95	0.60	0.60	None	None
			1.15	0.80	0.80	None	None
			1.25	0.90	0.90	None	None
			1.45	1.10	Beyond stand	None	None
			1.55	1.20		None	Faint
Distilled....	0	0	0.50	0.50	0.50	None	None
			0.75	0.75	0.80	None	None
			1.00	1.00	1.00	Faint	Faint
			1.50	1.50	Beyond stand	Decided	Decided

ship is so remote that the study of the curves brings out little of importance. Oxygen consumed values conform to the same general trend of turbidities and chlorine absorption values. The important fact is that all these different factors show a greater or less correlation which substantiates our view of the chlorine absorption method in practical use.

Bottle experiments such as above are not entirely satisfactory as the results obtained do not always parallel actual practice, but this series of experiments tends to show the comparative behaviour of the various types of water under similar conditions. In other words, we are not of the opinion that 1.10 p.p.m. chlorine could be left in the filtered water, as these experiments indicate, and not have taste. These experiments tend to show the extent of chlorine absorption and comparative taste limits of the four types of water.

The river water at the particular time of test had a very high chlorine absorption figure. Likewise settled and filtered water also had high absorption figures.

The points of interest brought out by these experiments are (1) Turbidity does not show much relation to the chlorine absorption value. (2) Large amounts of residual chlorine may be left in the filtered water without causing taste. (3) Impracticability of chlorinating river water. (4) Accuracy with which the chlorine absorption test and residual chlorine tests may be manipulated.

With respect to turbidity in its relation to chlorine absorption values, it is noted that the river, settled and filtered waters have turbidities of 22, 20, and 0 p.p.m. respectively, whereas their chlorine absorption figures are 1.00, 0.55 and 0.35 p.p.m. Other data gathered from plant operating results show that there is no direct relationship between the two. It is true, however, that if river water turbidity increases the chlorine absorption value tends to increase, but the converse is not necessarily true. The same conclusion is true of the settled water.

It may be noted that, according to experiment, the filtered water may have 1.20 p.p.m. residual chlorine before taste develops. In all probability this would not be true under plant operating conditions, although the chlorine absorption value would be quite high, probably as high as 0.75 p.p.m. In the case with the distilled water 1.00 p.p.m. may be present when faint taste develops. With the river and settled waters the taste limits are somewhat higher due to the presence of large amounts of organic matter and consequent irregular absorption of the chlorine.

It is evident, from results with river water, that it would be impracticable to chlorinate such a water, as it would use excessive quantities for absorption and as the residual test is so very indefinite it is questionable whether disinfection would be efficient under such conditions.

It is rather satisfying to note in the experiment with settled, filtered and distilled waters how accurately we are able to add chlorine and test back the exact excess in the residual test. This fact gives the worker confidence that such chlorine tests are reliable and can be utilized in a practical way.

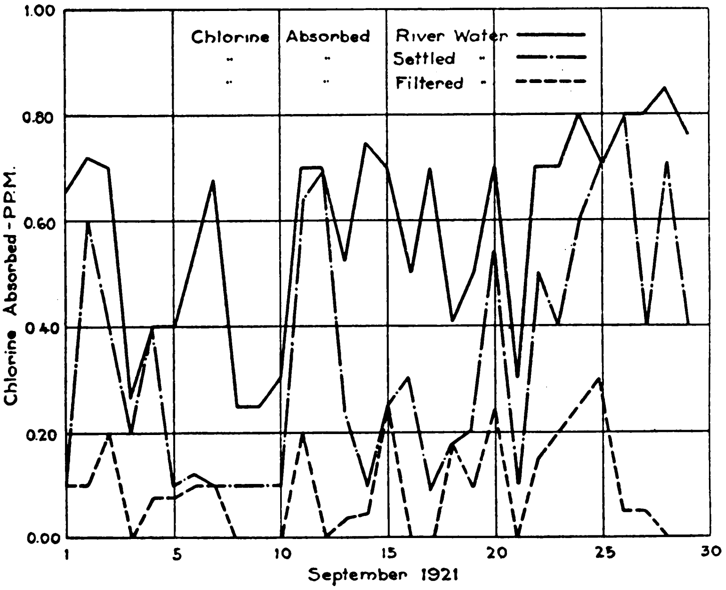

FIG. 2. DAILY VARIATIONS IN CHLORINE ABSORBED BY WATERS AT DIFFERENT STAGES OF TREATMENT

The method of making the chlorine absorption test is similar to that outlined by Wolman and Enslow,[4] with a slight modification. To 200 cc. of the water sample (at 20°C.) to be treated, add a sufficient volume of chlorine solution to give a resulting dose of 1 p.p.m. Shake vigorously after stoppering and allow to stand 5 minutes. Immediately shake again for second and transfer 100 cc. to a beaker containing 1 cc. of ortho-tolidin reagent. Place the beaker containing the sample and color reagent in a warm place for 12 minutes.

Dilute 10 cc. to 100 cc. volume and compare with permanent standards.

To test for residual chlorine take 100 cc. volume of water under test and add to it 1 cc. ortho-tolidin. Let stand in warm place for 12 minutes, then dilute 10 cc. to 100 cc. volume and compare with permanent standards.

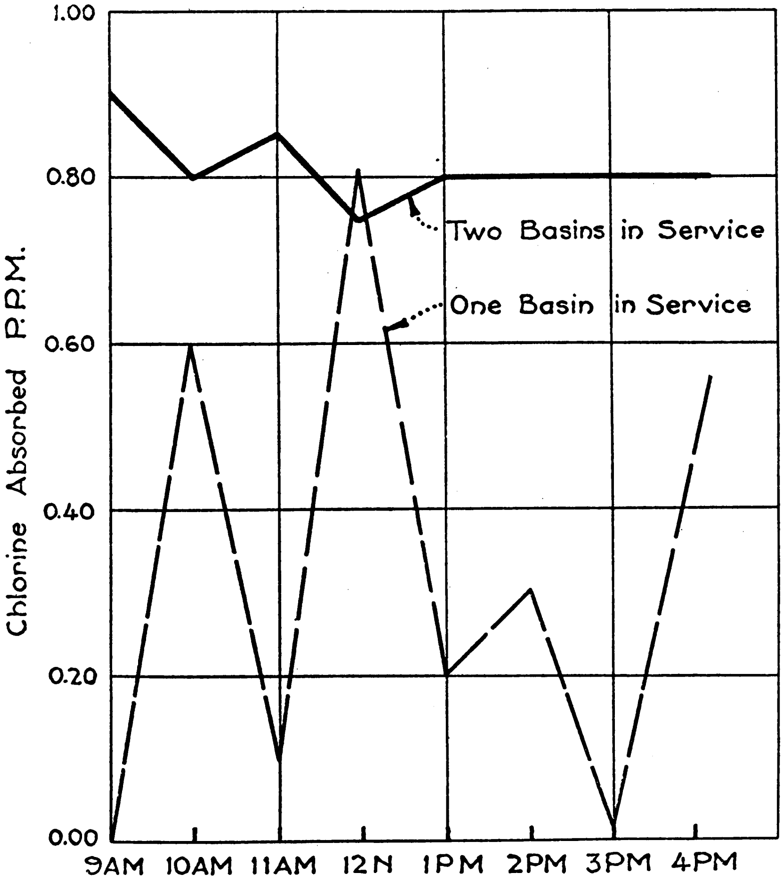

FIG. 3. EFFECT OF RETENTION PERIOD OF WATER ON ITS CHLORINE ABSORPTION

Further notes. In figure 2 chlorine absorption values of the river, settled and filtered waters are plotted for a period of one month. The month of September, 1920, was chosen as a representative month of the year, in that the river water characteristics and plant operating conditions were normal. These curves point out the maximum and minimum values and show how variable such chlorine absorption values are under actual conditions from day to day.

Figure 3 shows the effect of different basin retention periods on the chlorine absorption of settled water. The two-basin curve represents a normal plant operating condition for a period of 7 hours. Conditions represent an intermittent lime treatment, basins in parallel and approximately a 4-hour basin retention period.

The one basin curve shows what happens to chlorine absorption of settled water when the largest basin is used alone. Conditions in this case represent intermittent lime treatment with the basin retention period greatly reduced.

With two basins in service, a chlorine feed could be satisfactorily applied. With one basin in service, it is evident that great difficulty is experienced in properly disinfecting and at the same time in keeping water free from chlorine taste.

Control of the chlorine feeds was changed on May 24, from the "invariable dosage" plan to the plan of control as suggested in this paper. This change increased our feeds from a 0.65 p.p.m. application of available chlorine to 1.0 p.p.m., which was consistent with the chlorine absorption of the water at that time. In making this change bacterial results have not been what was anticipated due to temporary conditions prevailing as shown in a part of figure 3. With the change back to normal condition of the settling basins we have every reason to expect a more perfect disinfection to result. To date this changed feed has given no trouble due to tastes.

Summary

1. Where plant design is not well adapted for chlorinating, tastes are likely to be a result of improper feeding.

2. Grand Rapids experience shows that comparatively large doses of chlorine are necessary to disinfect, because of the presence of large amounts of organic matter capable of absorbing chlorine.

3. Where the plan of invariable dosage is followed there is great danger of running into taste difficulties. Chlorine absorption studies show the range between the necessary amount of chlorine for disinfection and the amount to give taste to be small.

4. Some method of controlling chlorine feed is shown to be necessary. Without such a method, the results at Grand Rapids show the danger of running into taste difficulties and inefficient disinfection.

5. The chlorine absorption method, as outlined by Wolman and Enslow,[4] is consistent and accurate.

6. Sixteen months experience with this testing method shows its practicability. It is the only quick method by which the chlorine demand of a water may be determined with accuracy. As far as this experience goes, chlorine demand as indicated by this method can be satisfied. Enough more may be added as excess to disinfect and yet keep away from taste.

7. While such characteristics as turbidity and oxygen consumed show only a general relationship, they all point to a consistency existing between them and the chlorine absorption values. This consistency argues well for confidence in the point of view taken by writers.

8. We believe the whole problem of tastes as applied to filtration plant practice is related to improperly proportioned dosages.